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LOCK-IN AMPLIFIER FOR NMR SIGNAL DETECTION

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BUDAPEST

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Abstract

A lock-in amplifier with 100 Kohm and 100 ohm input inpedances, built for the detection of signals in the presence of high background noise, is described. The minimum detectable signal is of order 1 nV for 10^{-20}W, generating 100 ohm input inpedance with an observation time of less than 1 min. The operating frequency can be varied per stage. The phase angle of the signal relative to the reference can be changed from a linear angular scale to better than ± 2 % accuracy.

Introduction

Lock-in amplifier techniques allow small changes in amplitude to the measured accurately, even for weak signals in the presence of high background noise (Dicke 1947, Andrew 1958, Moore 1962). The signal to be detected can be separated from the noise by a frequency demodulation that is synchronous with the period of the amplified signal and an RC filter with a time constant small as compared with the change in amplitude, but large relative to the modulation period. Such amplifier systems have been developed and already used for a variety of purposes. The relatively simple lock-in amplifier now described has been in use already for some years in the detection of nuclear magnetic resonance /NMR/ signals (Tompa and Tóth 1963).

The lock-in amplifier circuit

The block diagram and circuit diagram of the amplifier system are shown in Figs 1 and 2. The amplifier has two selective stages tuned essentially to the same frequency. This prevents the overdriving or saturation of the last stages by any spurious signal from the mains, or by any noise, even at maximum gain. Moreover, the output of the phase detector is not sensitive to any of the harmonics of the carrier frequency (Williams 1962.) The maximum gain of the voltage amplifier is 10^6 which can be decreased by the attenuator in steps of 10 dB. The operating frequencies are 35, 70, 140 and 280 Hz; 1,4 and 2,8 kHz. The amplifier frequency is determined by the LC filter in series with the negative feed--back circuit of the two stage amplifiers. The LC filter circuit is relatively easy to build in spite of the very low operating frequencies. The series tuned circuit has the advantage that the increase in either L or C involves hardly any change in the gain and thus the same inductor can be used with different capacitors for the tuning. The two successive, selective stages are tuned to slightly different frequencies. This leads to a smooth response in a narrow band around the resonant frequency and to a sharp drop in the characteristic past the operating frequencies. The response characteristic at 280 Hz which can be seen in Fig. 3, shows the selectivity of this amplifier system. At each frequency the band-width is 10 % of the frequency band around the center frequency.

The reference channel includes a three-stage phase shift circuit. In the first stage the phase is shifted by a constant angular value while the second and third stage are variable phase shifters. The phase shift to be obtained per stage was chosen to be 100°. Assuming a 1:10 variation of the resistance, this can be achieved only if the initial phase shifts are relatively high /60°/. These initial phase shifts produced by both variable phase shifters are compensated by the constant phase shift stage so that the phase of the reference signal can be adjusted by a uniaxial double potentiometer in the range from -10° to $+190^{\circ}$ at any frequency. In view of the accurate requirement of the phase angle, potentiometers of non-linear characteristic are used. The slope of the characteristic varies with the inverse of the angular phase response. The relative phase angle thus obtained for the linear angular scale can be read to $\pm\ 2^{\circ}$ accuracy.

The circuit diagram of the fully transistorized version of the system with maximum gain of order 10^6 is shown in Fig. 4. The main parameters are the same as in the earlier circuit.

Performance

The minimum detectable signal is limited only by the systematical noise figure of the amplifier. The variation of the noise level with the time constant of the RC filter is shown in Fig. 5. Line A shows the noise level measured with 100 kOhm impedance open input, line B that for short circuited input. Line C was measured by turning on and off an a.c. signal generator delivering signals of 0,60 μV amplitude. It is apparent that the signal to noise ratio improves with narrower band-width that, in turn, causes the response time to increase. At the systematical noise level the minimum input for signal detection /unity signal to noise ratio/ is estimated to be 10^{-20} W for the rated maximum response time /T $\approx$ 15 sec/ and 100 Kohm input impedance.

For low ohm sources the measurable signal amplitude can be minimized by transformer coupled input. Fig. 6 shows the variation of the signal to noise ratio measured using a secondary tuned input transformer with a turns ratio 1:100 and switching on and off a signal generator delivering signals of 0,01 μV amplitude with a 100 ohm input impedance and a filter response time of 15 sec. The minimum input power for signal detection is about the same as without transformer but the minimum detectable signal amplitude is of order 10^{-9} V. The linearity of the gain in amplitude is better than 0,2 % at any phase angle.

Acknowledgments

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Figure Captions

Fig. 1 Schematic diagram of lock-in amplifiér system

Fig. 2 The lock-in amplifier circuit

Fig. 3 Response of selective amplifier at 280/Hz frequency

Fig. 4 The transistorized selective amplifier circuit

Fig. 5 Output signal and noise of the lock-in amplifier for 100 Kohm input impedance as a function of filter response time. A/ open input, B/ short circuited input, C/ alternatively with and without 0,60 μV input signal

Fig. 6 Signal to noise ratio of the lock-in amplifier for transformator coupled input. Generated impedance 100 ohm, input signal 0,01 μV, filter response time 15 sec

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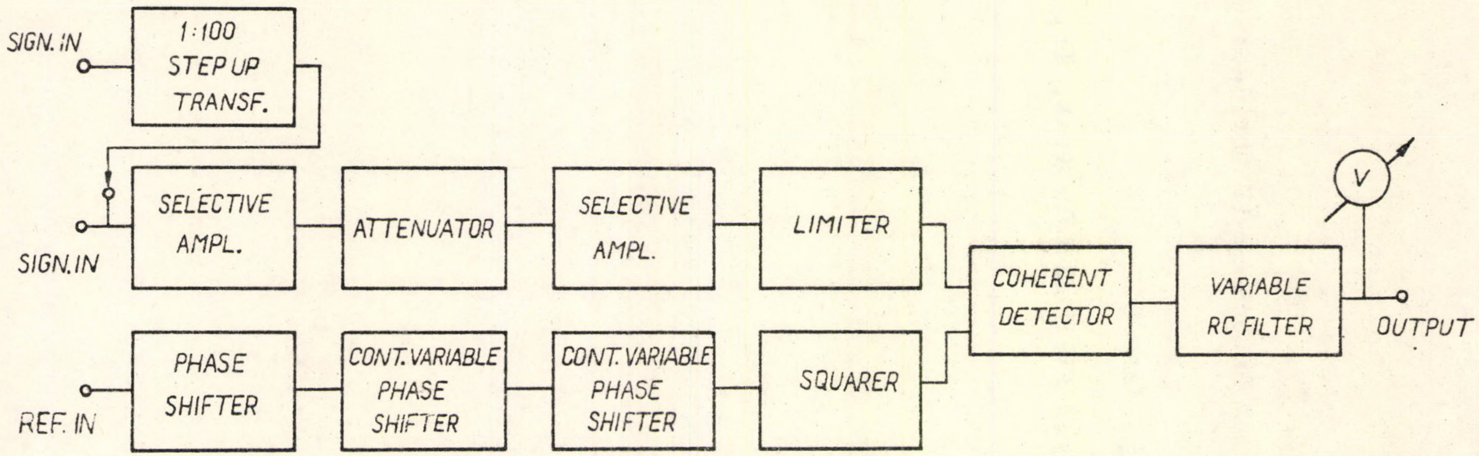
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RC FILTER
V
OUTPUT
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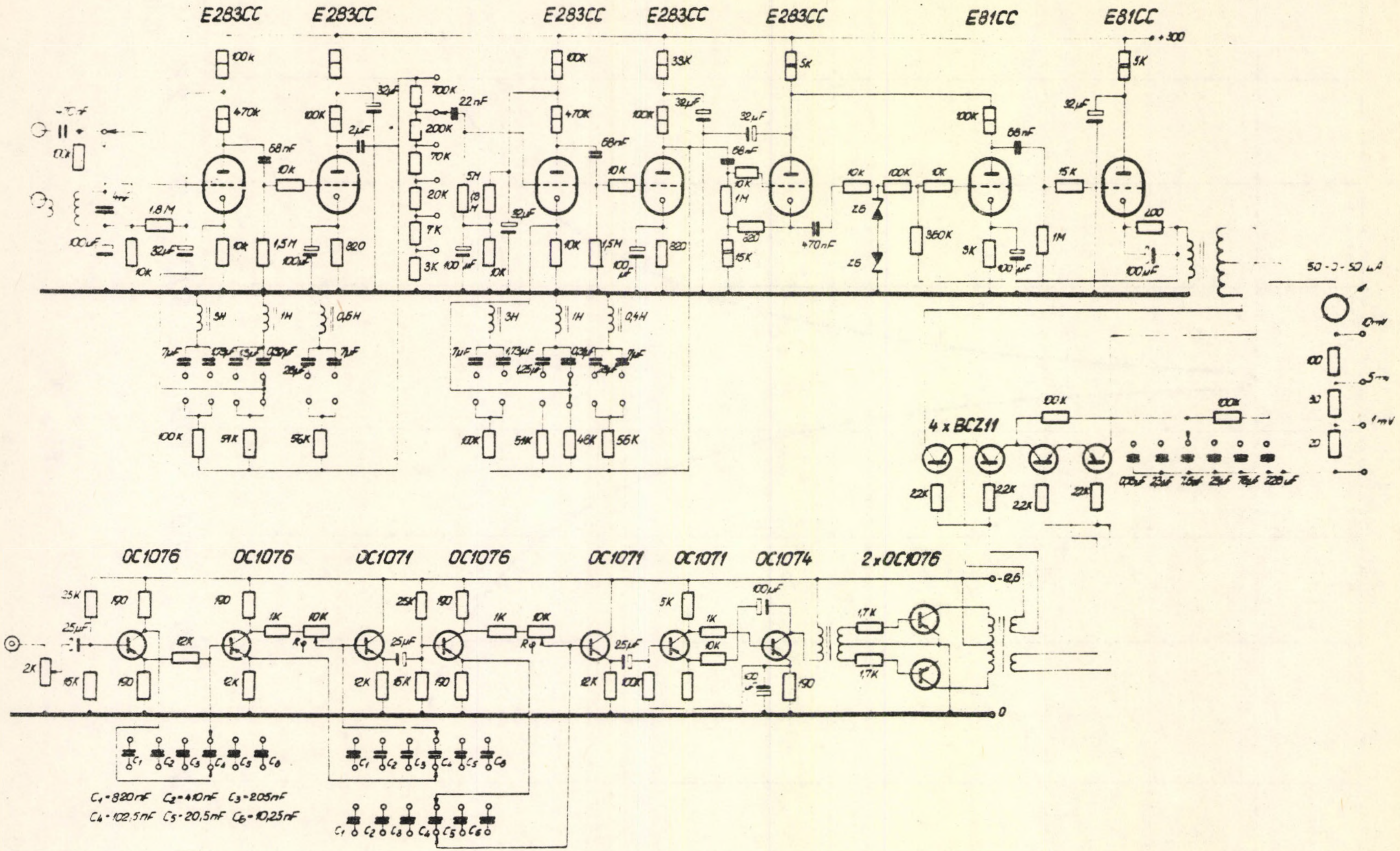
Fig. 1.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OC1076
OC1076
OC1071
OC1076
OC1071
OC1071
OC1074
2 x OC1076
-12,6
0
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C4 = 102,5nF C5 = 20,5nF C6 = 10,25nF

Fig. 2.

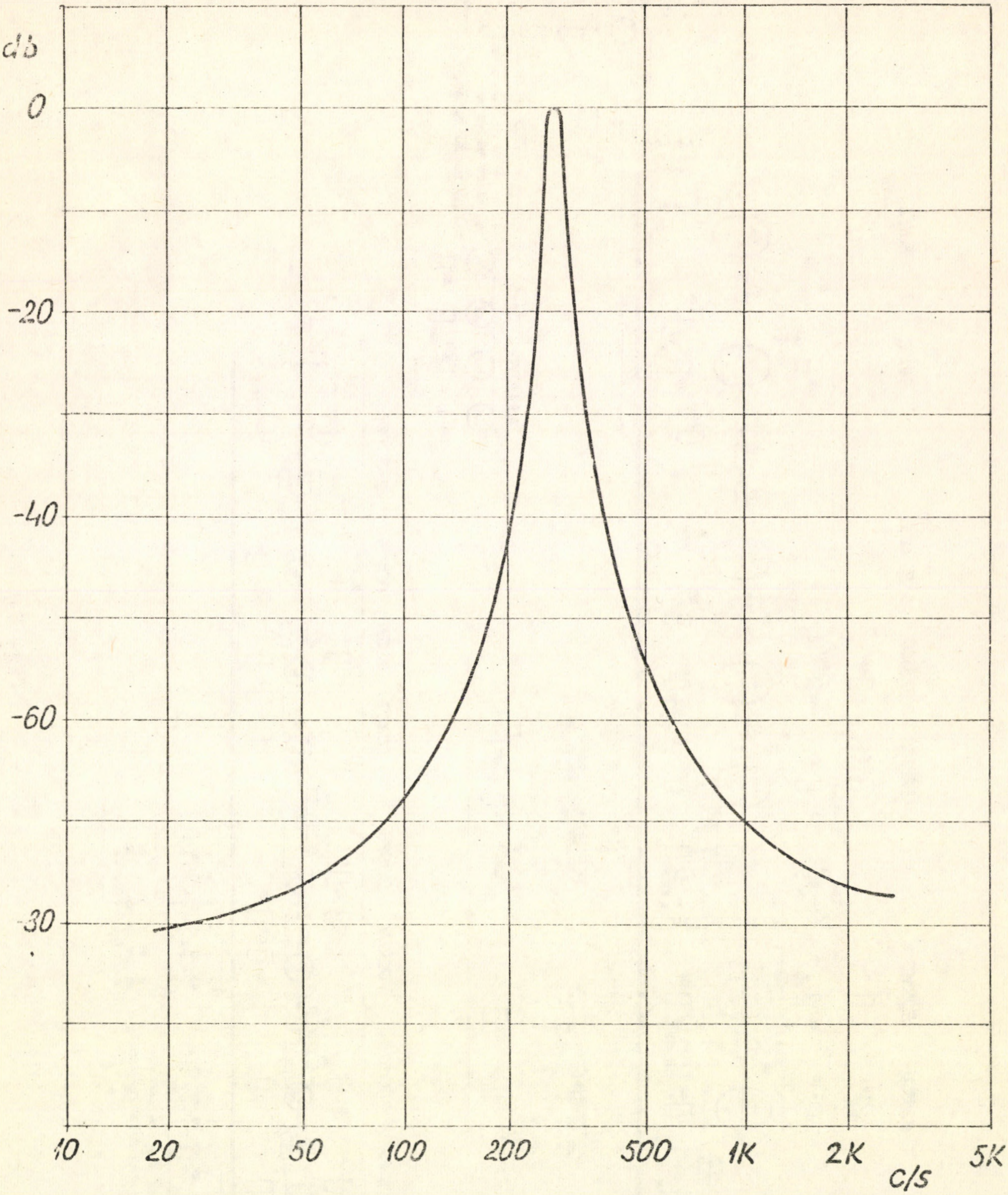
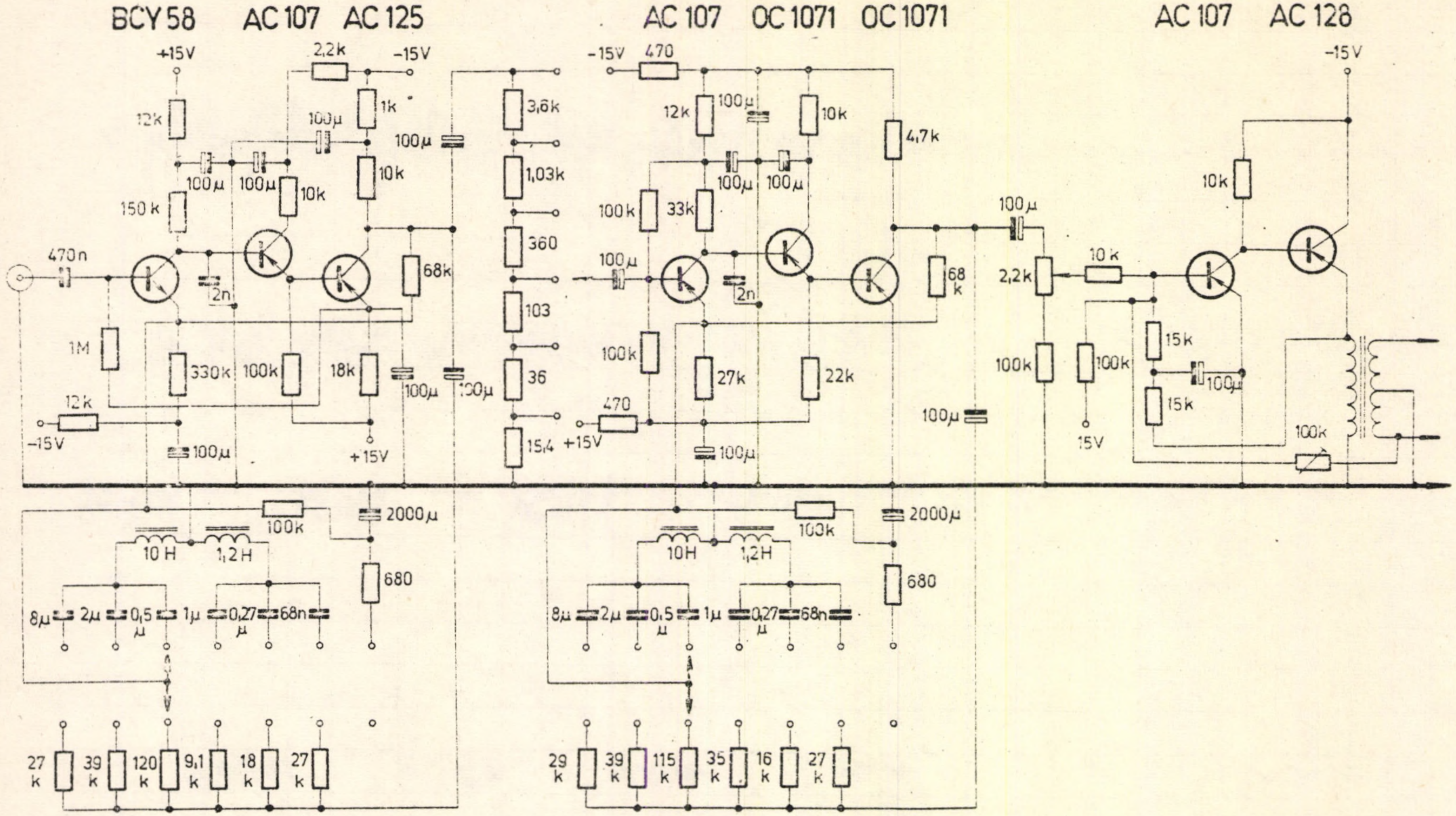


Fig. 3.



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AC 125
AC 107
OC 1071
OC 1071
AC 107
AC 128
+15V
-15V
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12k
1k
100μ
10k
150 k
470n
2n
68k
1M
330k
100k
18k
12k
100μ
+15V
3,6k
1,03k
360
103
36
15,4
470
33k
4,7k
27k
22k
68 k
2,2k
10 k
15k
15V
100k
10 H
1,2 H
2000μ
680
8μ
2μ
0,5 μ
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16 k

Fig. 4.

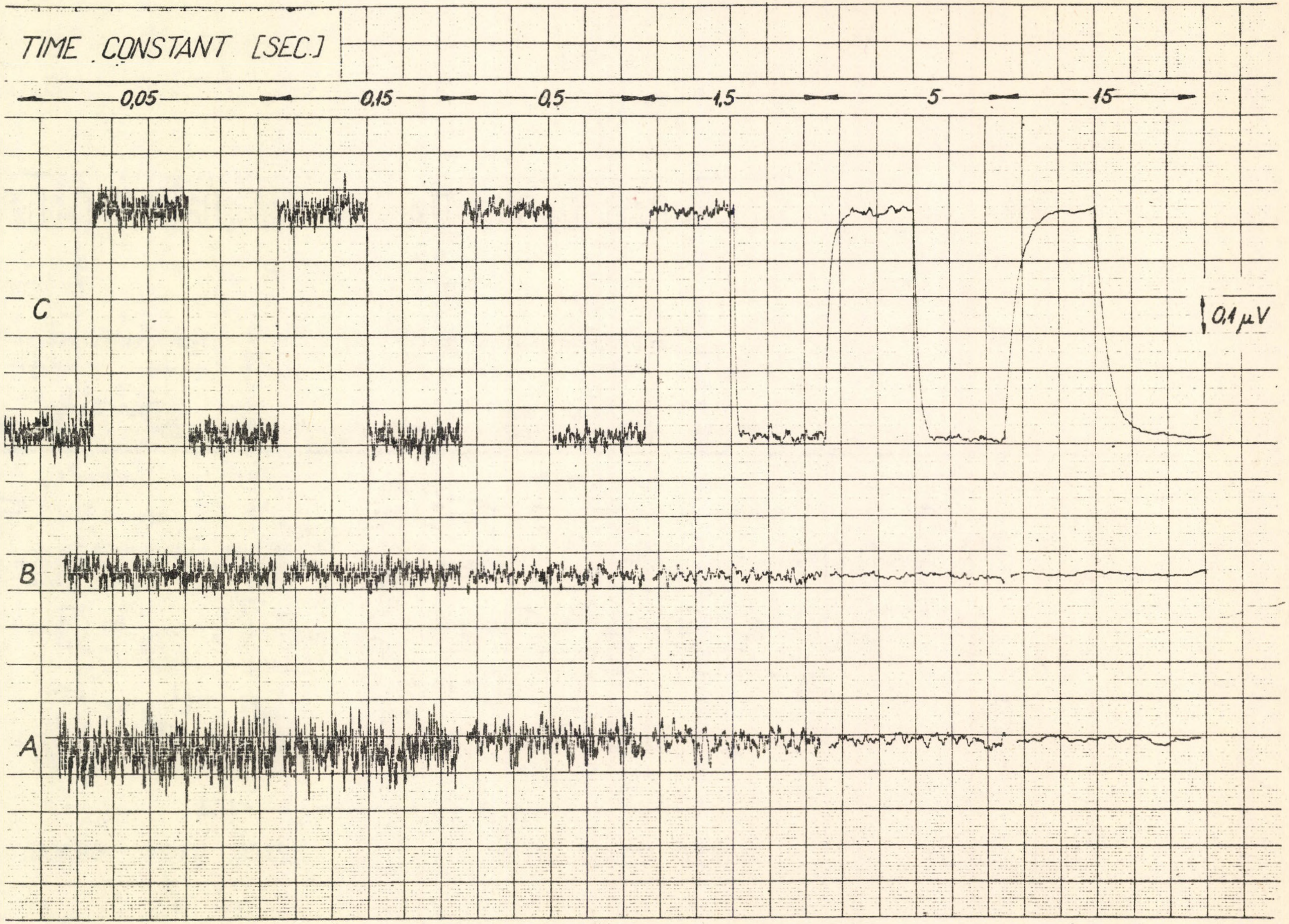

Fig. 5.

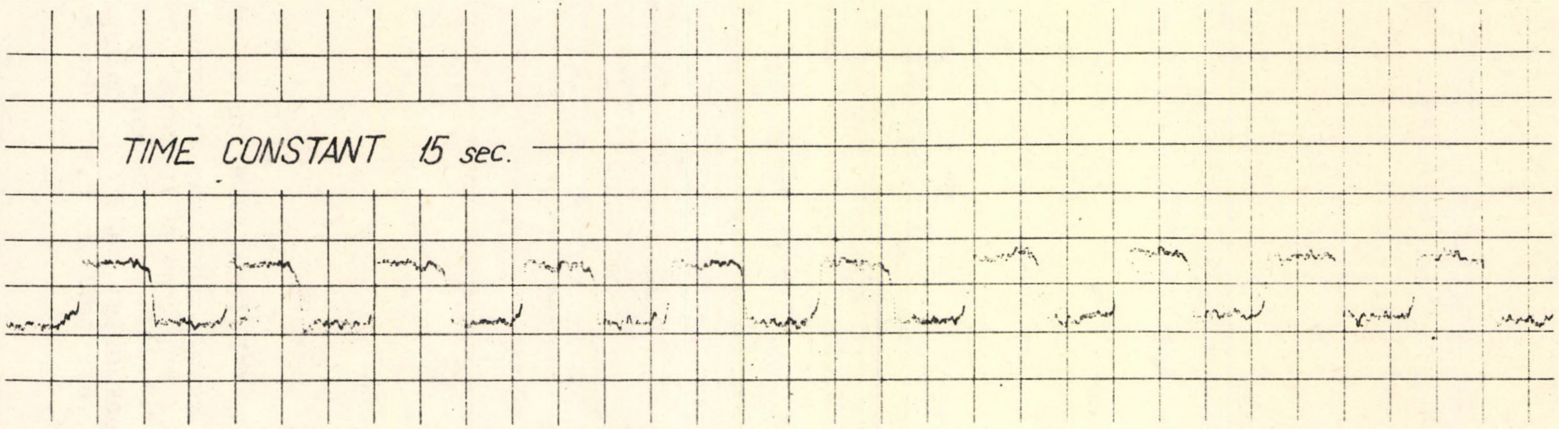

Fig. 6.

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